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Bulkheading Effects on Radon Release from the Twilight Uranium Mine

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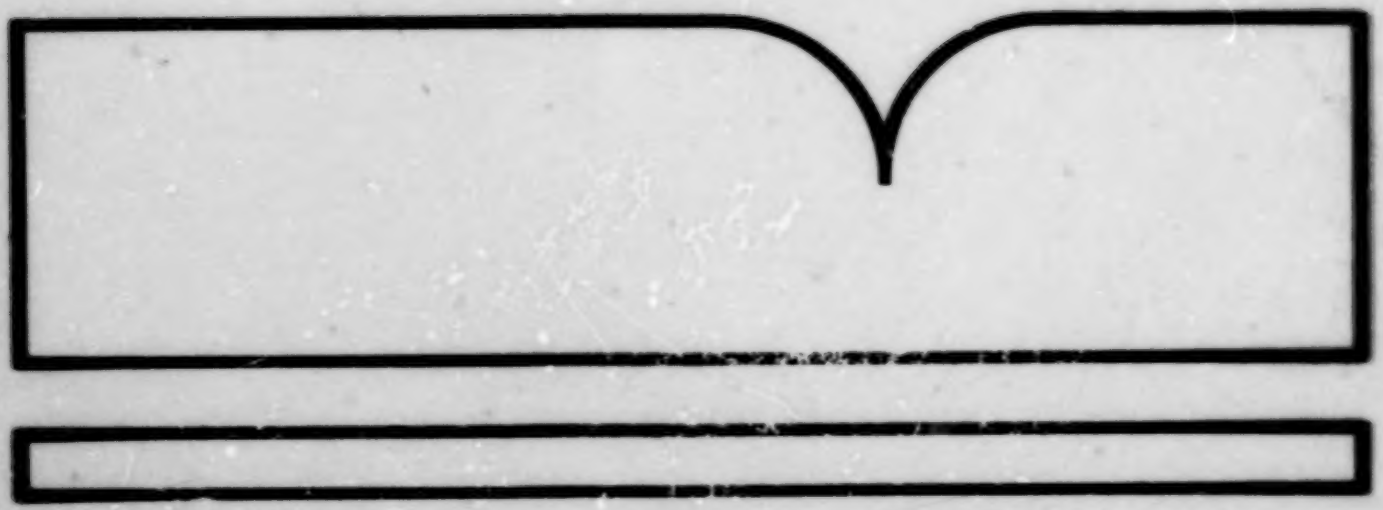

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BULKHEADING EFFECTS ON RADON RELEASE FROM THE TWILIGHT URANIUM MINE

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16. ABSTRACT

A study was made to determine the effects of bulkheading on radon release from an underground uranium mine during both exhausting and blowing ventilation. The continuous radon measurements were made with and without a large portion (about 40 to 45%) of the mine totally or partially bulkheaded for consecutive periods of up to 2 weeks. These measurements showed that bulkheading produced a major effect on the total radon leaving the mine and that this effect was dependent upon the type of ventilation and the integrity of the bulkheads.

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BULKHEADING EFFECTS ON RADON RELEASE FROM THE TWILIGHT URANIUM MINE

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ABSTRACT

A study of the effects of bulkheading on the radon release from an underground uranium mine was conducted at the Bureau of Mines underground uranium research mine. The research mine is known as the Twilight Mine and is located near Uravan, Colorado. The air flow conditions included exhausting and blowing ventilations with and without bulkheading for six consecutive experimental periods of up to 2 weeks each. Radon measurements in mine and exhaust air were made for both directions of air flow with bulkhead doors at either end of an internal loop open, closed, and closed but with a major leak. These measurements show that bulkheading produced a major effect on the total radon leaving the mine and that this effect was dependent upon the type of ventilation and the integrity of the bulkheads. During exhausting ventilation, the total radon discharged from the mine decreased by 17% when the bulkhead doors were closed but with a large leak. A further reduction of 35% was observed when the large leak was closed. This latter measurement, however, was made over a very short time period and radon had not built up to its maximum equilibrium concentration. During blowing ventilation, a small (6%) but not significant increase in the total radon leaving the mine was measured when the bulkhead doors were closed but with the large leak. When the large leak was eliminated, a reduction of 35% was observed. Other parameters affect the total radon leaving the mine which must also be taken into consideration when interpreting these measurements, including barometric pressure. A small amount of air was pumped from the bulkheaded area of the mine to maintain a negative pressure. This air, with its relatively high radon content, could be passed through a sorption trap or discharged at a high elevation to minimize exposure to people

in the environs. If this air were passed through absolute sorption traps, it could reduce the radon leaving the mine to 45% and 68%, respectively, of that for exhausting and blowing ventilation with no bulkheading.

INTRODUCTION

One of the procedures used in underground uranium mining to reduce exposure of miners to the naturally occurring radon and its short-lived daughters is a technique referred to as bulkheading.[1,2] A portion or portions of the mine that have been "mined out" and are therefore inactive are sealed off from the active portions of the mine by building walls or bulkheads across the inactive stopes or drifts. A negative pressure is normally maintained behind these bulkheads to insure that any leakage at the bulkhead will be into bulkheaded areas. This effectively isolates the miners from the radon emanations accumulating in the bulkheaded area.

The exhaust ventilation rate required to maintain the slight negative pressure behind the bulkheads is small compared with the additional ventilation that would be required without the bulkheading. The concentration of radon can build behind the bulkheads to orders of magnitude greater than that in the active portions of the mine, and the fraction of radon which decays in these areas can be substantial. When the bulkheaded area is kept at a slightly negative pressure (nominally 0.03 cm water) with respect to the active areas, the air being pumped from behind the bulkhead, which contains very high radon concentration, can be released to the environment outside the mine or passed through a radon sorption trap prior to release.

The purpose of this study was to determine the effect of bulkheading on radon release from an underground uranium mine during both exhausting and blowing ventilation. The continuous radon measurements were made with and without a large portion (about 40 to 45%) of the mine totally or partially bulkheaded for consecutive periods of up to 2 weeks.

EXPERIMENTAL PROTOCOL

The Twilight Mine (Figure 1) just north of Uravan, Colorado, was selected as the site for the investigation. This mine is leased from Union Carbide by the Bureau of Mines and is operated as a research mine for the Bureau

of Mines by the Adare Contracting Company. The Twilight Mine is small, with two entry portals connected to each other by a single loop drift about 360 m in length (Figure 1). Two internal loops have been mined off from this main loop. The larger of these, which is about 250 m in length, is equipped with bulkheads at either end. Each end can be opened or closed by doors. The bulkhead at 1L9 is penetrated by two small diameter pipes (5 cm and 8 cm) which are normally used to pump water and/or diesel fumes into the bulkheaded portion of the mine for experimentation purposes. In this study one of these pipes was used to provide a negative pressure of about 0.03 cm of water behind the closed bulkheads with respect to the rest of the mine. A larger (60 cm) pipe penetrates both bulkheads and can be opened or closed by means of louvered shutters.

The main ventilation fans are located at Portal B. They may be reversed to provide either exhausting ventilation or blowing ventilation. In the experiment, exhausting ventilation rates averaged 390 m^3/min and blowing ventilation averaged 550 m^3/min. The experiment was conducted in four major phases using two modes of ventilation:

Phase I:	Exhausting ventilation with bulkhead doors open
Phase IIA:	Exhausting ventilation with bulkhead doors closed, 60 cm pipe shutters open (leaky bulkhead)
Phase IIB:	Exhausting ventilation with bulkhead doors closed, 60 cm pipe shutters closed
Phase IIIA:	Blowing ventilation with bulkhead doors closed, 60 cm pipe shutters open (leaky bulkhead)
Phase IIIB:	Blowing ventilation with bulkhead doors closed, 60 cm pipe shutters closed
Phase IV:	Blowing ventilation with bulkhead doors open

Measurements were made during the course of this investigation using instruments provided and operated by SRC, in addition to those installed by PNL. The monitoring equipment was operated and maintained during the course of the study by the Adare Contracting Company.

The following continuous measurements were made throughout the four phases of the experiment in addition to those at the exhaust portals (see Figure 1).

Station 1 - Radon concentration, air velocity
Station 2 - Radon concentration, air temperature, barometric pressure
Station 3 - Radon concentration
Station 4 - Radon concentration
Station 5 - Radon concentration, air velocity
Station 6 - Radon concentration

This monitoring instrumentation located at the above stations is described elsewhere by Franklin.[3] In addition, two Eberline Continuous Radon Gas Monitors, Model RGM-1, were used to measure radon concentrations at Stations 0 and 7 and at bulkheads 1L7 and 1L9, dependent upon the experimental conditions. Vane anemometers and hot-wire anemometers were used to make spot measurements of air velocities at selected places in the mine.

This mine is situated about 30 m below the top surface of a mesa. Measurements of radon flux from the ground above the bulkheaded area were made during 24-hour periods with and without the bulkheads being closed to check for increased radon flux at the surface due to possible faults or fissures from the mine. A fissure reaching to the surface from the bulkheaded area would be expected to emanate much more radon than the surrounding areas, especially when the bulkhead doors were closed and without negative pressure in the bulkheaded area.

Radon flux measurements from the surface of the mesa above the mine were made using a charcoal canister technique similar to that reported by Countess[4] (GMA 457315 canister: Mine Safety Appliance Co.). An array of canisters was set out in a grid pattern starting at drill hole J316 and the canisters were separated by about 30 m (Figure 2). The canisters were sealed to the ground by pushing a cylindrical edge into the ground 1 to 2 cm. Exposure times were 24 hours. After exposure, the canisters were sealed and shipped to our laboratory for ^{222}Rn measurement based on gamma-ray spectrometric analysis for its ^{214}Bi and ^{214}Pb daughters.

In addition to measuring radon concentrations, 400 g quantities of an inert tracer (freon 12) were released into mine inlet air during each of the

four phases of ventilation described earlier to measure the time required to transport gases from portal to portal and their streaming effects. For these analyses, samples of the mine exhaust air were collected at timed intervals after each release and analyzed for freon-12 concentrations by gas chromatographic techniques. Measurement of freon in the air being pumped from behind the bulkhead served to indicate the degree of leakage across the bulkhead.

DISCUSSION AND CONCLUSIONS

The freon release experiments described above provided two useful pieces of information. First, it was learned that a very slight negative pressure (0.03 cm water) in the bulkheaded region caused mine air to leak from the "active" area of the mine into the bulkheaded area. Relative concentrations of freon-12 measured in air being pumped from behind the bulkheaded area during portions of Phase IIIA and Phase IIB are presented in Figure 3. The freon released in the active portion of the mine was, within minutes, detected in the air being pumped from the bulkheaded area. Second, after a single spike release at the intake portal under each of the four sets of ventilation conditions described earlier, the time required to reduce the concentration of freon-12 at the outlet portal by 50% was half as long with the bulkhead doors closed as with them open (Figures 4 and 5). Removal of 95% of the freon tracer took three to four times longer with the doors open than when closed. The data indicated, at least for 50% removal of the tracer, that clearance time under exhausting ventilation was faster than under blowing ventilation.

Radon flux measurements on the surface of the mesa above the bulkheaded portion of the mine were comparable during a 24-hour period when the bulkhead doors were open under exhausting ventilation, and a 24-hour period when the bulkhead doors were closed under blowing ventilation. The small changes in radon flux which were observed are probably attributable to normal variations between days. The flux measurements obtained are presented in Table I. No large changes in flux of the magnitude to be expected from possible fissures were observed though average radon concentration behind the bulkhead doors was a factor of 300 higher when the bulkhead doors were closed than when they were open. Thus the integrity of the mine appears sound.

TABLE I. Radon Flux Measured on Mesa Above Twilight Mine, Uravan, Colorado

SAMPLE	^{222}Rn, pCi/cm^2-sec ± 1σ *	
	EXHAUSTING VENTILATION, DOORS OPEN	BLOWING VENTILATION, DOORS CLOSED
NW-2	7.4×10^{-5}	1.2×10^{-4}
NE-2	$9.8 \times 10^{-6} \pm 4.6 \times 10^{-6}$	$4.4 \times 10^{-5} \pm 5.3 \times 10^{-6}$
NW-1	2.2×10^{-5}	$4.0 \times 10^{-5} \pm 6.0 \times 10^{-6}$
N-1	2.4×10^{-5}	$4.3 \times 10^{-5} \pm 5.7 \times 10^{-6}$
NE-1	6.3×10^{-5}	$1.9 \times 10^{-5} \pm 4.8 \times 10^{-6}$
NW-0	7.5×10^{-5}	4.1×10^{-5}
N-0	9.3×10^{-5}	1.4×10^{-4}
N-V**	3.8×10^{-3}	Not sampled
NE-0	$5.2 \times 10^{-5} \pm 5.4 \times 10^{-6}$	$4.6 \times 10^{-5} \pm 6.3 \times 10^{-6}$
SW-0	9.0×10^{-5}	$7.4 \times 10^{-5} \pm 6.7 \times 10^{-6}$
S-0	$4.3 \times 10^{-5} \pm 4.9 \times 10^{-6}$	$6.1 \times 10^{-5} \pm 6.0 \times 10^{-6}$
SE-0	7.0×10^{-5}	1.4×10^{-4}
SW-1	6.4×10^{-5}	1.8×10^{-4}

* Counting Uncertainties Less than 5% Unless Given

** Old Drilling Hole (J-316) Adjacent to N-0

Figures 6 through 11 compare barometric pressure and the quantity of radon leaving the exit portals during the six study periods. Diurnal variations in radon concentrations are easily recognized as are inverse correlations of radon concentration with barometric pressure changes. There are also some discontinuities in the data due to inadvertent ventilation fan shutdowns and during stabilization periods after changing experimental conditions from one phase to another. The data are sufficient, however, to clearly show the effects of the bulkheading procedure.

During exhausting ventilation with the bulkhead doors open (Phase I), the radon leaving the mine averaged 75 μCi/min (Table II). Closing the bulkhead doors but leaving the 60 cm pipe shutters open (leaky bulkhead) reduced that average amount by 17% to 62 μCi/min. Closing the 60 cm pipe shutters (Phase IIB) resulted in a further reduction of 35% for a total of 52% reduction from the open bulkhead condition. As mentioned earlier, the radon concentration behind the bulkhead had not come to an equilibrium state by the time Phase IIB measurements were made. At equilibrium, the radon concentration behind the bulkhead might be 5 to 10 times higher which would certainly change the 52% reduction in radon to a smaller figure, possibly on the order of 30 to 40%. In addition, while the average barometric variations during Phases I and IIA are comparable, the barometric pressure went through a very steep increase just prior to Phase IIB and remained at a relatively high pressure throughout Phase IIB. This may tend to reduce radon emanation from the mine and thus reduce radon leaving the mine. It was found that closing the bulkhead doors and the shutters did not completely isolate the bulkhead area, and so these conclusions describe a bulkhead with small leaks. Even with this situation, there is a real and important reduction in radon release to the environs.

During blowing ventilation with the bulkhead doors open (Phase IV), the radon leaving the mine averaged 79 μCi/min. Closing the bulkhead doors but leaving the 60 cm pipe shutters open (leaky bulkhead) (Phase IIIA) resulted in an apparent increase of 6% from the open-door condition to 84 μCi/min. We do not consider this change to be significant as it may be due to average barometric change differences between the two periods. Closing the 60 cm pipe shutters (Phase IIIB) reduced the average total radon leaving the mine

Table II. AVERAGE RADON IN VENTILATION AIR FROM THE TWILIGHT MINE

Experimental Conditions	Measurement Period (days)	Exhaust Air from Bulkhead Area		Exhaust Air from Total Mine		Ratio of Bulkhead Area Radon to Total Mine Radon
		Flow Rate m^3/min	^{222}Rn $\mu Ci/min$	Flow Rate m^3/min	^{222}Rn $\mu Ci/min$	
Phase I Exhausting Ventilation Bulkhead Doors Open	16	66	42	390	75	0.56
Phase IIA - Exhausting Ventilation Leaking Bulkhead	11	None	--	390	62	--
Phase IIB Exhausting Ventilation Bulkhead Doors Closed	0.15	1.5	2.5	390	36	0.07
Phase IIIA Blowing Ventilation Leaking Bulkhead	6	None	--	560	84	--
Phase IIIB Blowing Ventilation Bulkhead Doors Closed	5	1.5	1.2	540	55	0.02
Phase IV Blowing Ventilation Bulkhead Doors Open	13	58	30	560	79	0.38

to 55 μCi/min for a total reduction of 30% from the open-door condition.

When the bulkhead doors were open, exhausting ventilation resulted in an average radon emission of 5% less than blowing ventilation. We feel that this small difference is not significant and may simply be due to minor differences in the average barometric pressure.

To understand the significance of the radon measurements in Table II, one must again consider the lengths of the experiment during which radon was measured. All of these time periods except one ranged from 5 to 16 days, and thus the ratio of radon being released from the bulkheaded area relative to the total mine was probably representative. In Phase IIB, however, the period of this experiment was only about 3-1/2 hours. During this period of time, the bulkhead doors and the 60 cm pipe shutters were closed but the radon in the bulkheaded area had not begun to approach equilibrium. If the experiment had been allowed to continue for several days, the amount of radon being exhausted from the bulkheaded area would certainly have increased. To place this in perspective, we have estimated the approximate amount of air in the bulkheaded area. We estimate this amount may be on the order of 5000 m^3. Since the ventilation rate from the bulkheaded area is 1.5 m^3/min, then this would be equivalent to a daily exchange of the air. One could, therefore, expect a considerably larger build-up in radon concentration than was observed during the 3-1/2 hour period of the test.

In Phases IIA, IIIA, and IIIB of the experiment, measurements were conducted over periods of from 5 to 11 days and, therefore, the radon release from the bulkheaded area would more closely represent that at equilibrium.

Phase IV was simply a test with the bulkhead doors open, and the data for this were accumulated over a 13-day period and should certainly be representative. The important thing to recognize from these experiments, however, is that the radon which is discharged from behind the bulkheaded area at relatively low flow rates could be captured by use of sorption traps if the economics were favorable* or it could be released at a relatively high

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*The technical aspects of the sorption of radon on charcoal beds appear to be favorable[5], but it is beyond the scope of this study to evaluate the economical feasibility of the procedure.

altitude, say 15 to 25 meters.[6] In either case, the opportunity for exposure to individuals at ground level would be reduced.

As can be seen from the data in Table II with bulkhead doors closed and with exhausting IIB and blowing IIIB ventilation, a very major reduction in radon release would be achieved if the radon from the bulkheaded region were captured on a sorption trap. For these experimental conditions, the total radon released with bulkheading and trapping would be 45% and 68% of the non-bulkheading situation for exhausting and blowing ventilation, respectively.

It seems important to compare the potential of bulkheading in a large active mine with the observations made in this very small-scale study. Whereas the experimental mine had somewhat comparable areas of active and inactive regions, an actual working mine may have worked-out regions with tens of times more volume than the working regions. It can thus be surmised that effective bulkheading of active mines could reduce radon emissions by up to an order of magnitude, or perhaps more. If a study were to be conducted at an active uranium mine, one should be selected where the potential for bulkheading of a substantial region of the mine volume is possible. Discussions with mine operators have indicated their willingness to participate in a study if a well-conceived experiment could be devised. From considerations of active mines, it appears that suitable ones are available and that a study which would include the cooperation of the mine operator and ourselves could be productively carried out.

ACKNOWLEDGMENTS

The efforts expended in assisting PNL on this study by K. D. Weverstad and M. E. King of the Bureau of Mines, Spokane Research Center, and A. D. Hill of Adare Contracting Company are appreciated very much. Consultations with M. R. Petersen, who performed the freon analyses, and P. O. Jackson, both of PNL, were very helpful. Data processing was greatly enhanced by the contribution of J. W. Brothers of PNL.

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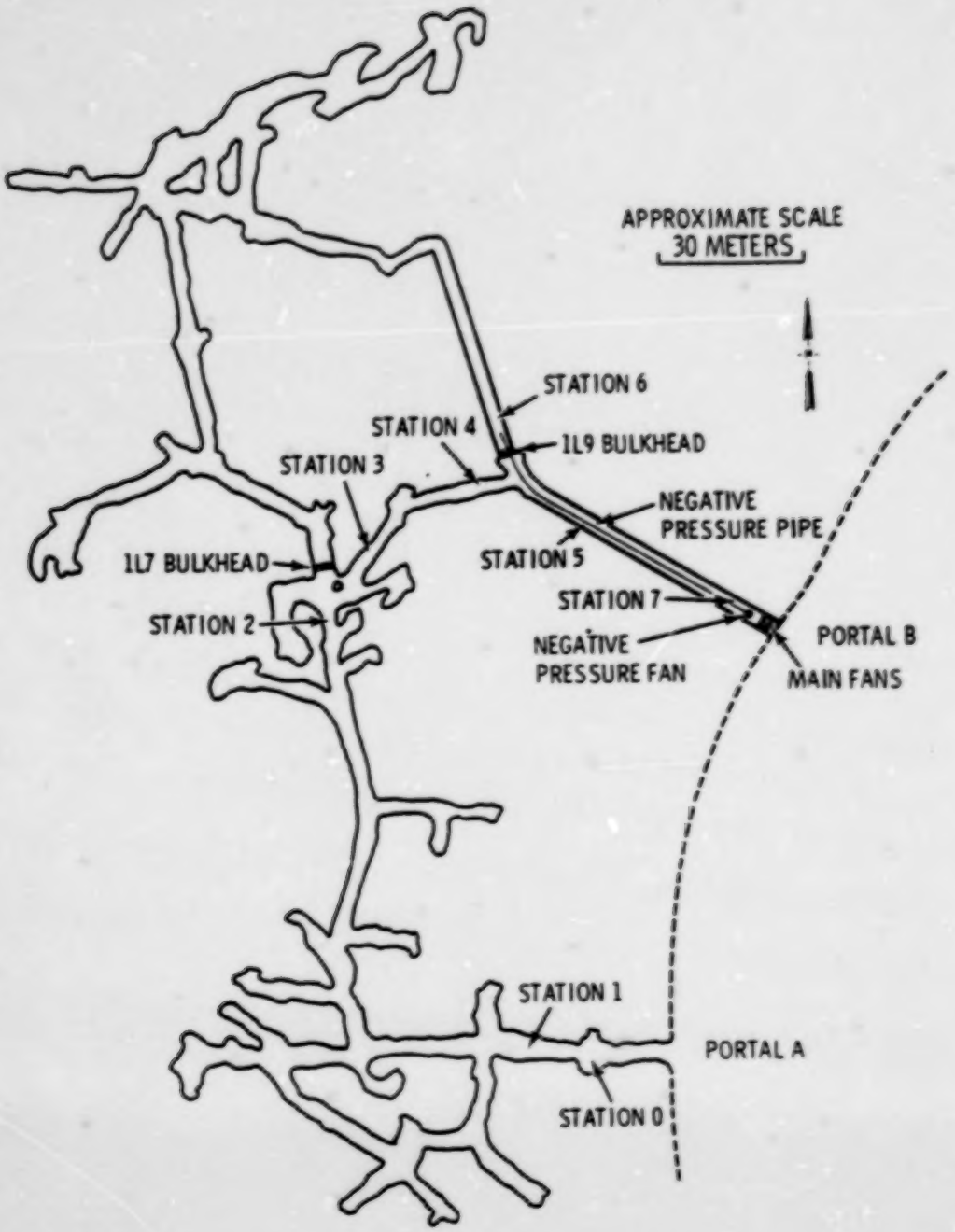

Figure 1. Twilight Mine, Uravan, Colorado.

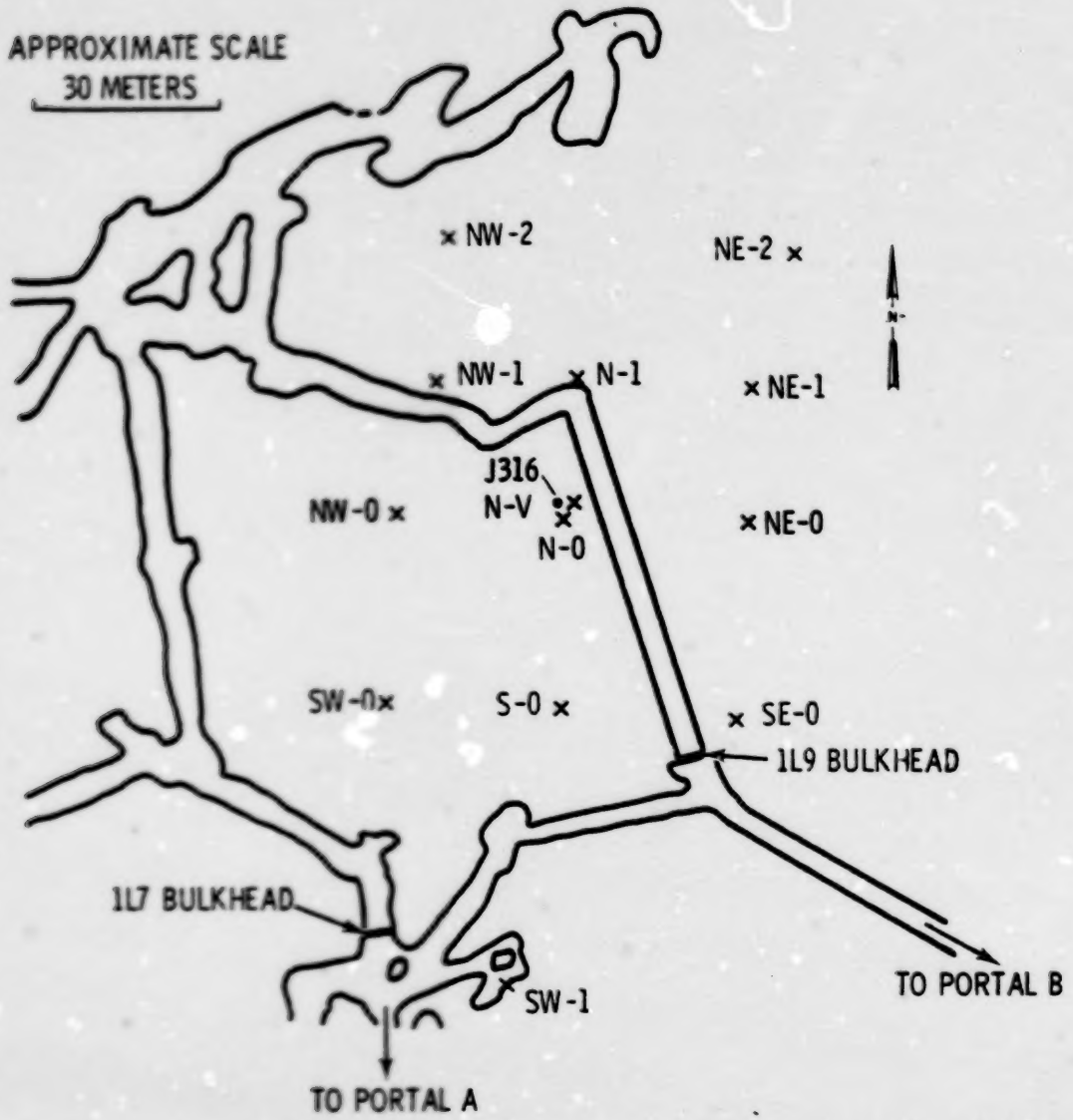

Figure 2. Approximate Radon Flux Sampling Sites on Mesa Above Twilight Mine

Depth from Mesa to Mine = 30 Meters

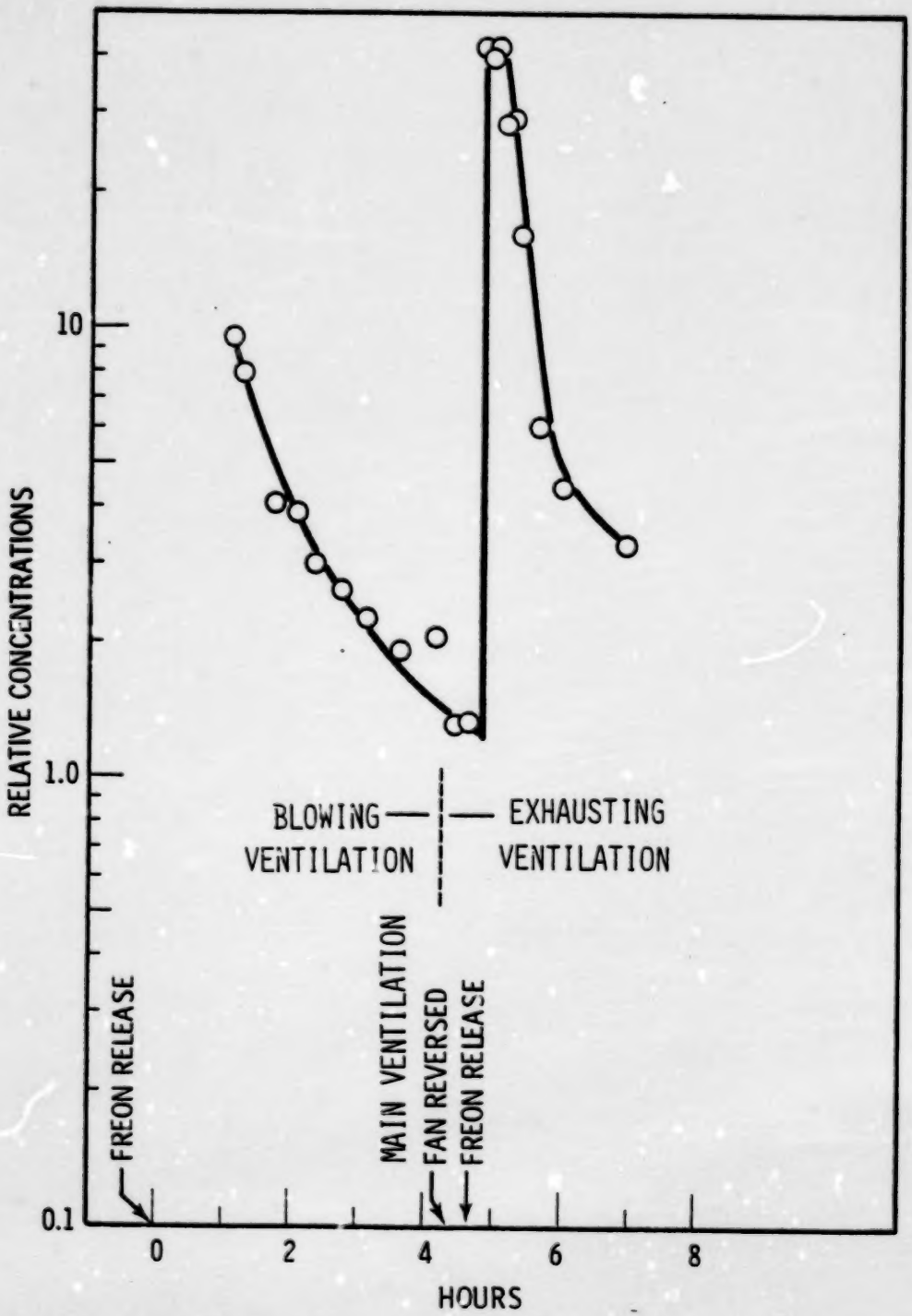

Figure 3. Freon Concentrations in Air Being Pumped from Behind the Bulkheaded Area During Portions of Phase IIIA and Phase IIB

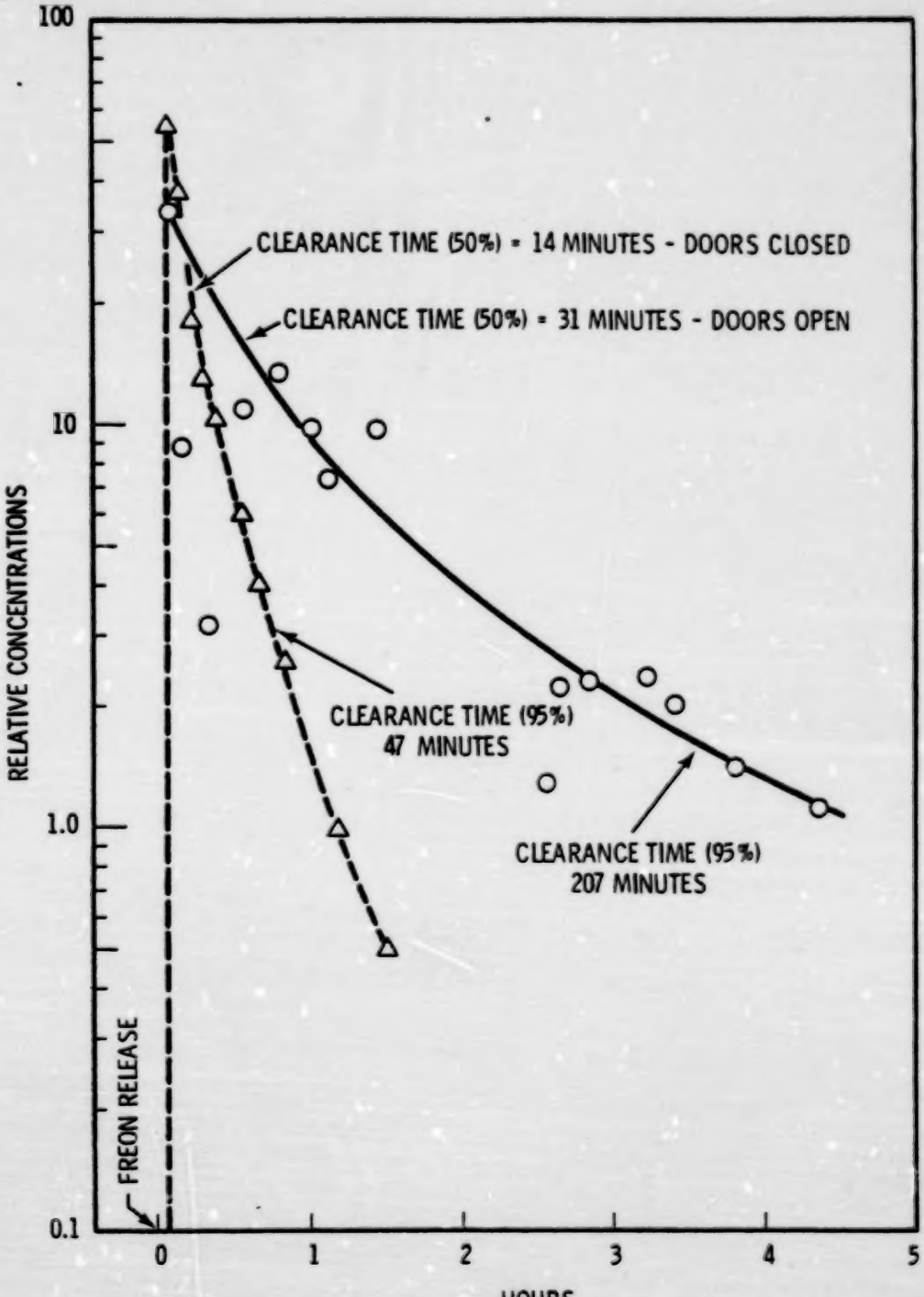

Figure 4. Freon Clearance Experiment During Exhausting Ventilation.

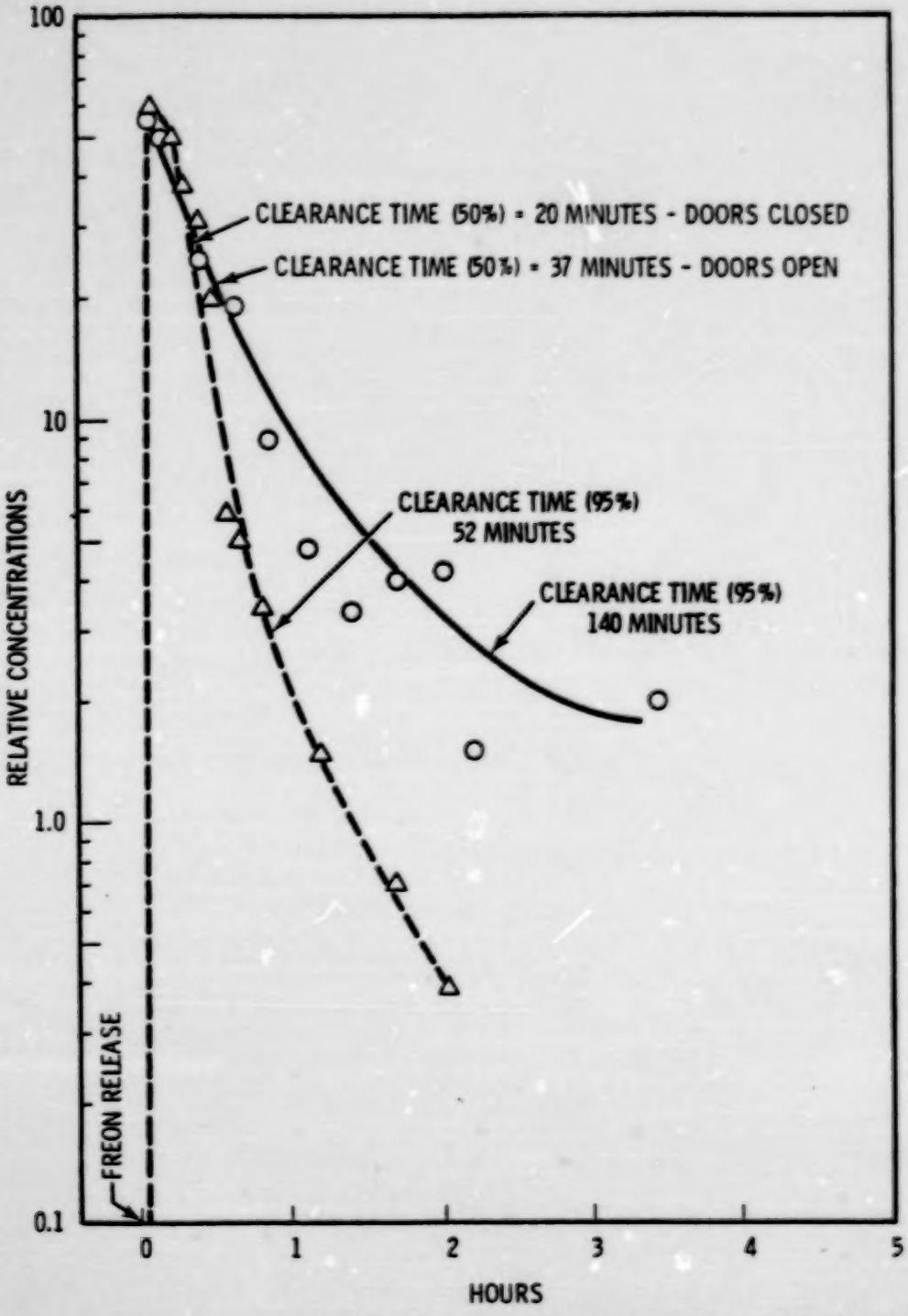

Figure 5. Freon Clearance Experiment During Blowing Ventilation.

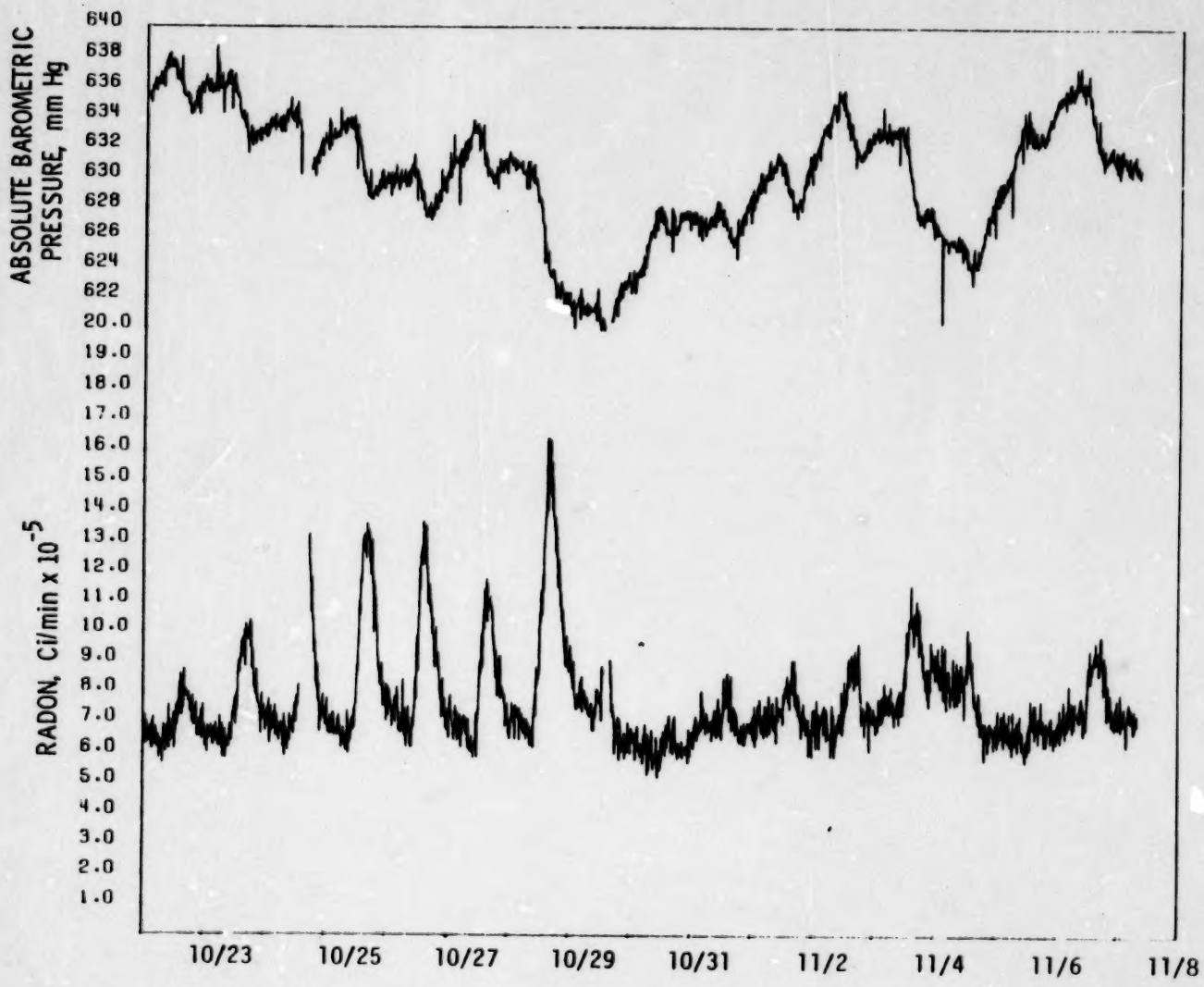

Figure 6. Phase I, Exhausting Ventilation, Doors Open

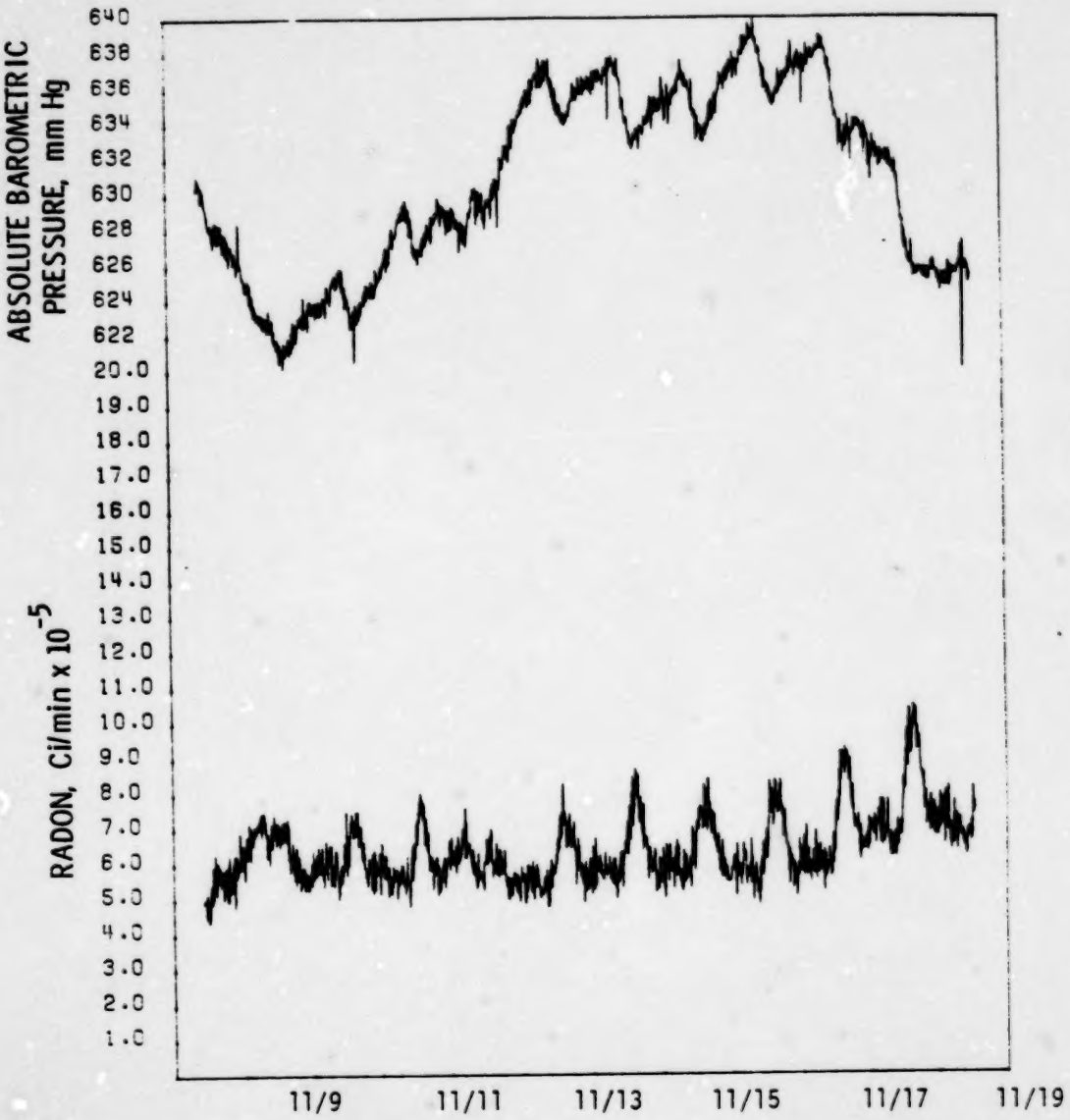

Figure 7. Phase IIA, Exhausting Ventilation, Doors Closed, 60 cm Pipe Shutters Open.

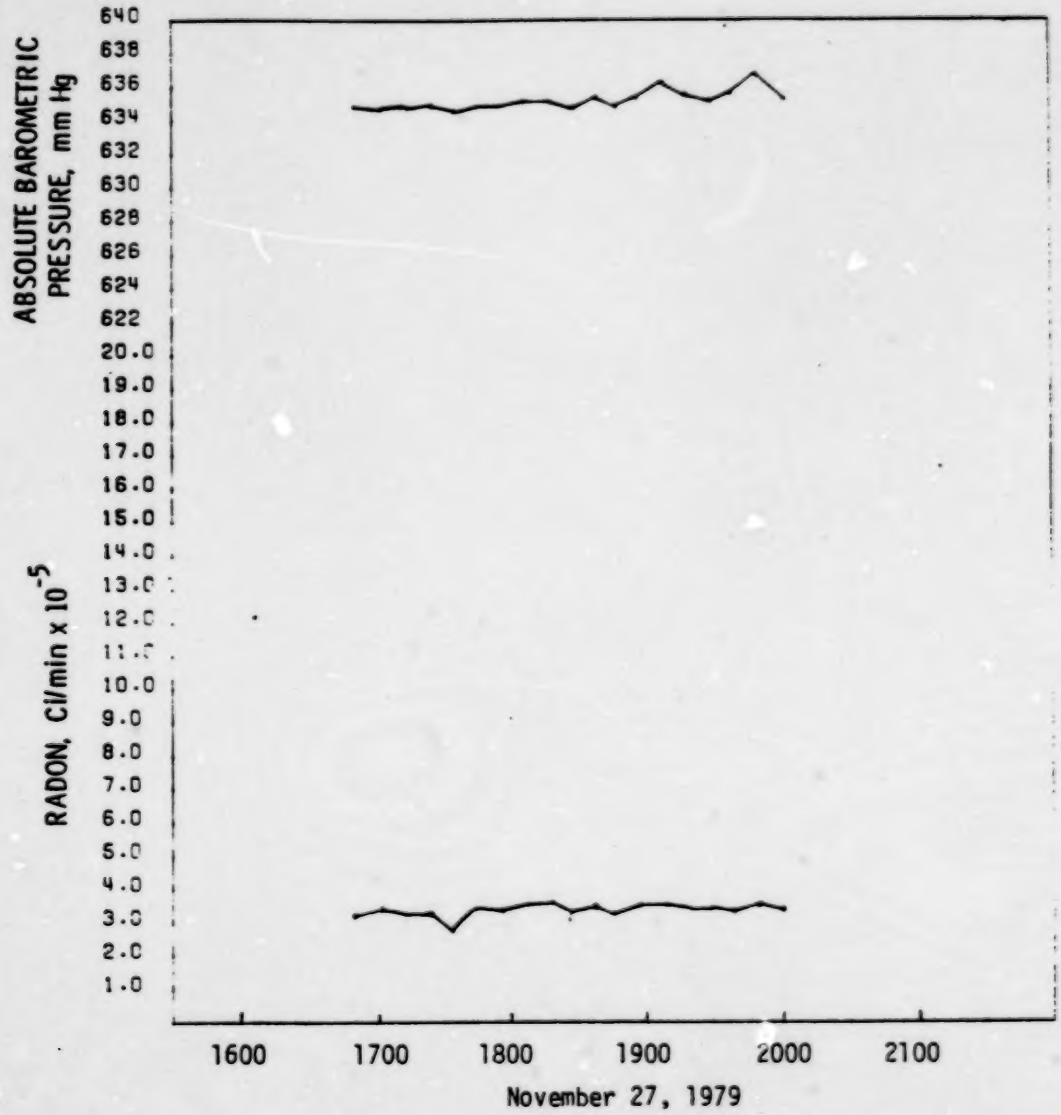

Figure 8. Phase IIB, Exhausting Ventilation, Doors Closed, 60 cm Pipe Shutters Closed.

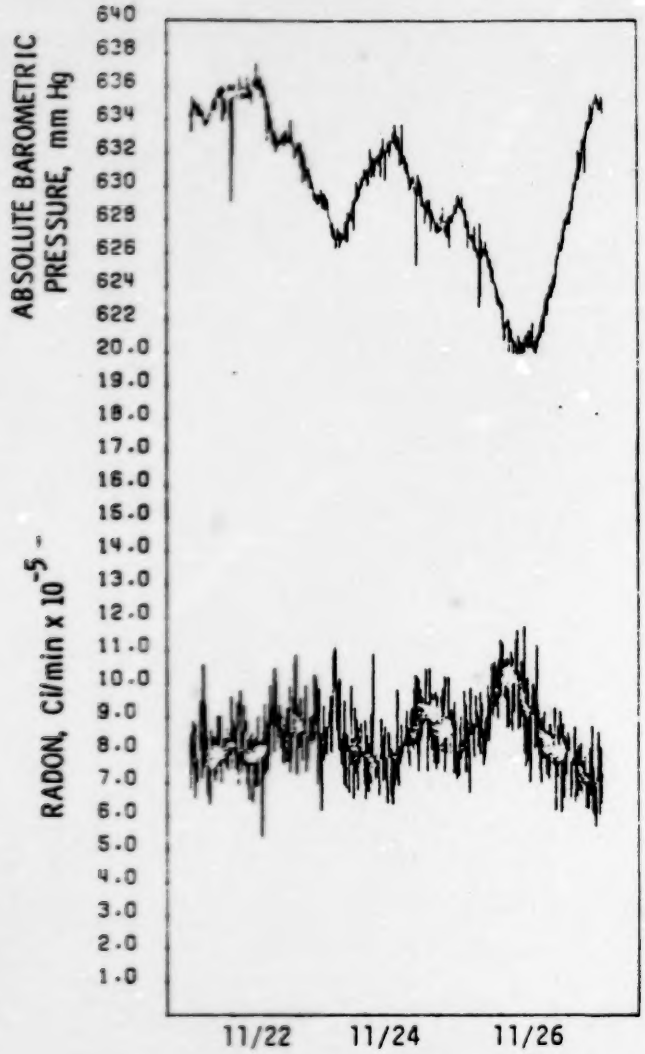

Figure 9. Phase IIIA, Blowing Ventilation, Doors Closed, 60 cm Pipe Shutters Open.

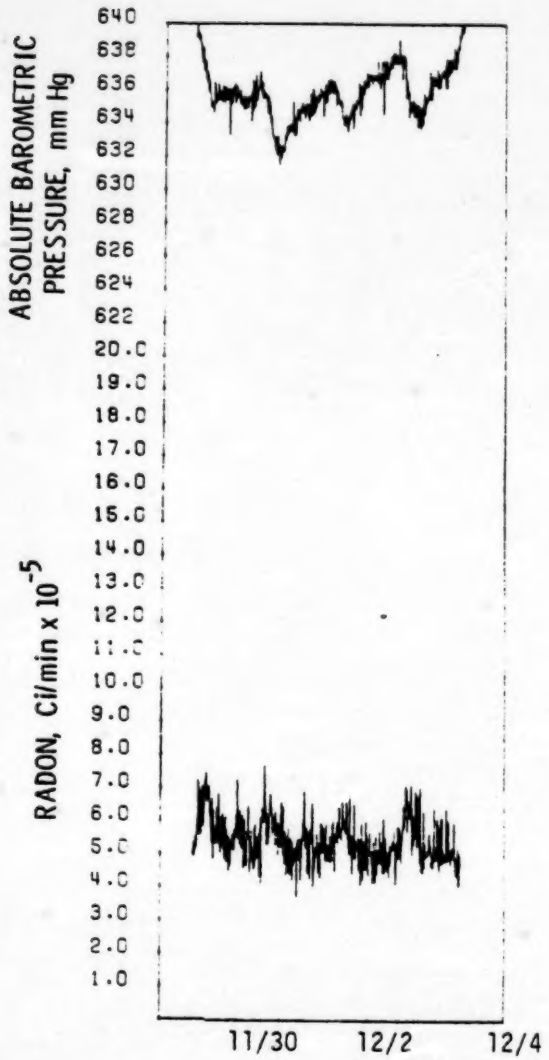

Figure 10. Phase IIIB, Blowing Ventilation, Doors Closed, 60 cm Pipe Shutters Closed.

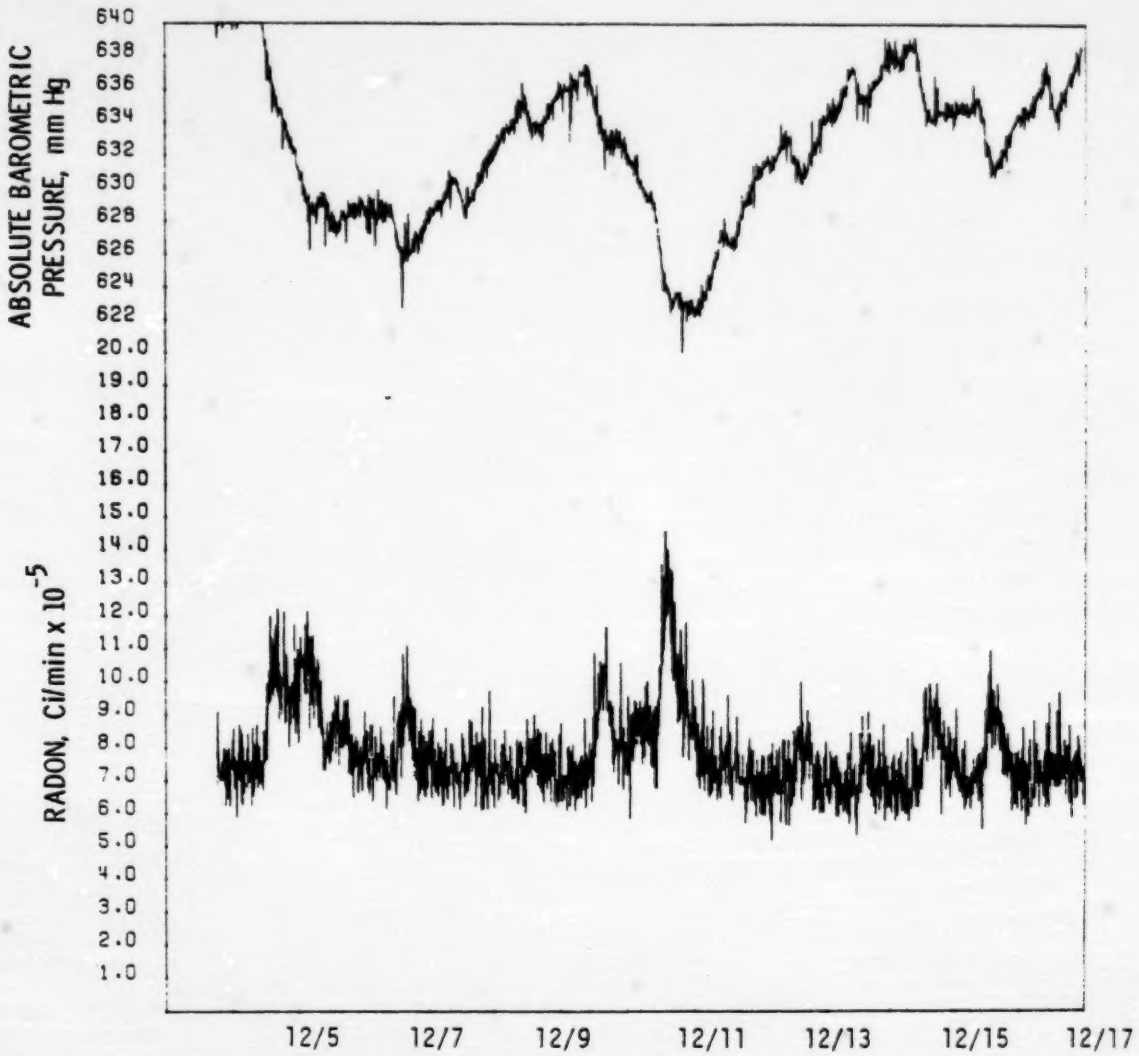

Figure 11. Phase IV, Blowing Ventilation, Doors Open.